Comparison of Huelsmann Basic Biquad with View to the Decrease of the Attenuation over the Transient Frequency of the Operational Amplifier

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Abstract: - The signal processing at discrete time requires an aliasing filter at the input and a reconstruction filter at its output. In this paper, selected basic structures of biquads are described and compared with a view to the decrease of the attenuation over the transient frequency of the operational amplifier. Concretely, low-pass and band-pass Huelsman (i.e. multi feedback) structure are confronted with the limits of a real operational amplifier. Firstly, the reasons of the decreasing of the attenuation are explained theoretically. Secondly, these conclusions are verified by simulations. These simulations were performed by spice-like circuit simulator MicroCap version 10.

Key Words: Low-pass, Band-pass Filters Structure, Real Operational Amplifier; Frequency Response, Decreasing of the Attenuation at High Frequencies.

1 Introduction

Circuits that process the signal at a discrete time, i.e. switched capacitor circuits, switched currents and digital signal processing circuits, [1] require for their operation an aliasing filter at the input and a reconstruction filter at its output. These filters should have low pass filter and/or (in special causes) band-pass properties, but the use in active RC (ARC) filters of the operational amplifiers with real properties will modify the monotone-decreasing frequency response.

Some biquad filters structures are characterized by a decreasing of the attenuation at high frequencies [2], [3]. This decreasing of the attenuation occurs only for the filters of the even orders, i.e. for the biquads.

The cause of these attenuation losses is depicted in Fig. 1 for a low-pass filter of the second order [4], [5]. The ideal case of the frequency response of the low-pass filter of the second-order is the decreasing of the magnitude over cut-off frequency ω_0 with -40 dB/dec slope. The finite value of the transient frequency ω_T of the used operational amplifier leads

to the break of this ideal slope. The result is a loss of attenuation in the stopband for the frequencies around the transient frequency ω_T.
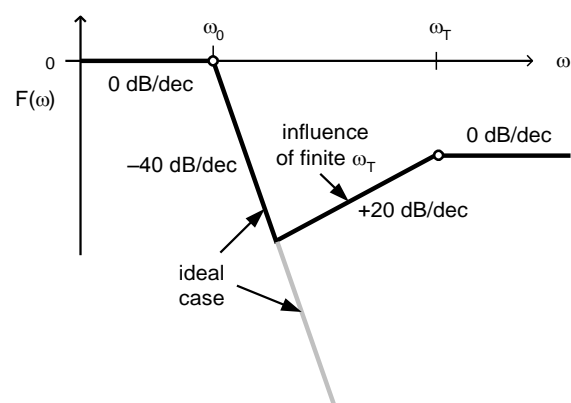

Figure 1. **Fig.1** Frequency response of the low-pass biquad.

Filter with a distributed feedback loop using only one operational amplifier in Huelsmann general structure is depicted in Fig. 2 [6], [7]. Its transfer function F simply derived from this circuit diagram

by signal flow graph (SFG) method (when the Mason formula is applied) is (1).
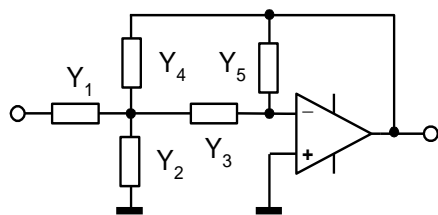
Figure 2.

Fig.2 General Huelsmann filter structure.

$$F = \frac{-Y_1 \cdot Y_3}{(Y_1 + Y_2 + Y_3 + Y_4) \cdot Y_5 + Y_3 \cdot Y_4}$$

(1)

where Y are admittances, i.e. there are realized from R and/or C members.

2 Problem Formulation

Next turn our attention into some Huelsman filter structure, where will be analyzed and decreasing of the attenuation at high frequencies will be discussed.

2.1 Low-pass Huelsmann filter structure

Generally, the members of low-pass filter structure are derived from equation (2) [8], [9], [10], [11], where on the left side is the Huelsmann filter general transfer function, on the right side low-pass the general transfer function.

$$\frac{-Y_1 \cdot Y_3}{Y_1 \cdot Y_5 + Y_2 \cdot Y_5 + Y_3 \cdot Y_5 + Y_4 \cdot Y_5 + Y_3 \cdot Y_4} =$$

$$= \frac{\omega_0^2}{s^2 + s \cdot \dfrac{\omega_0}{Q} + \omega_0^2}$$

(2)

where: Q is quality, ω_0 the corner frequency. Equation (2) nominator on the left side must be the real number because the nominator on the right side is the real number as well, therefore the admittances must be realized by resistors with the conductances as follows: $Y_1 = G_1$, $Y_3 = G_3$. Other admittances in the denominator can be choose as capacitors: $Y_4 = sC_4$, $Y_5 = sC_5$ and other as an resistor with the conductance $Y_2 = G_2$. In this case

(LP-H version 1), corresponding circuit diagram is depicted in Fig. 3.
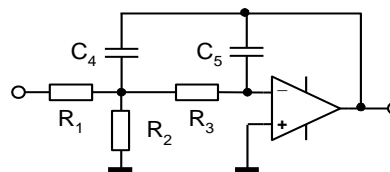

Fig.3 LP-H filter structure ver. 1.

Next, the circuit magnitude characteristics of this circuit diagram were analyzed by simulation, the program MicroCap version 10 is used, and the result is given in Fig. 4.
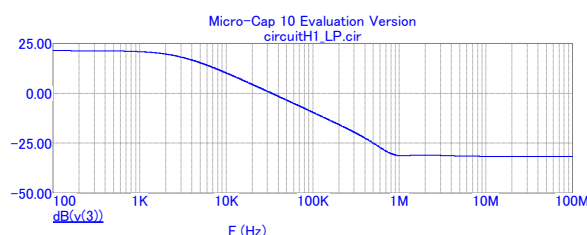

Fig.4 LP-H filter structure ver. 1 frequency response.

The output voltage of the frequency-independent divider: R_1, R_2 is exciting other parts of this circuit, thus output voltage LP-H filter ver. 1 is not zero at a higher frequency. As we can see, in this case, the structure has not unfortunately and monotone increasing attenuation in the stopband. The lowest attenuation the magnitude 30 dB only over the transient frequency ω_T seems very small, it is not so quite.

Consider now second one configuration (i.e. version 2), where nominator must be realized from resistors: $Y_1 = G_1$, $Y_3 = G_3$ as well, but in the denominator, we can choose as admittances: $Y_2 = sC_2$, $Y_5 = sC_5$ as capacitors and $Y_4 = G_4$ as the resistor. Thus, the corresponding circuit diagram is depicted in Fig. 5.
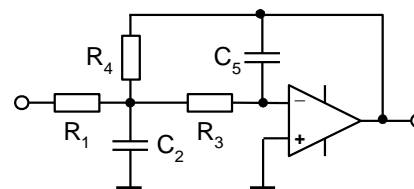

Fig.5 LP-H filter structure ver. 2.

The magnitude characteristic of this circuit diagram will be now analyzed with simulation by the

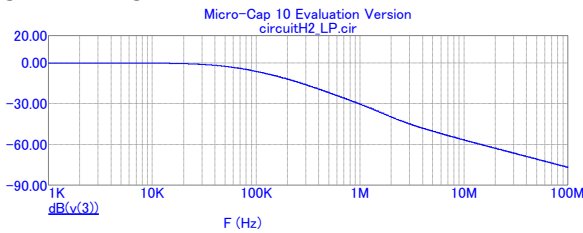program MicroCap version 10, and the result is given in Fig. 4.

Fig.6 LP-H filter structure ver. 2 frequency response.

The members: R_1, C_2 are frequency-dependent voltage divider, at highest frequency is capacitor: C_1 as short circuit, in this case: $V_{C2}=0$. Thus, its output voltage (i.e. V_{C2}) has a monotone increasing. As we can see from simulation, the biquad in this structure version 2 has a monotone increasing attenuation in stopband. Therefore, this version 2 is recommended for application.

2.2 Band-pass Huelsmann filter structure

In some cases, it is necessary to use the band-pass filter as well. Generally, the members of low-pass filter structure are derived from equation (3), where on the left side is the Huelsmann filter general transfer function, on right side the band-pass general transfer function.

$$\frac{-Y_1 \cdot Y_3}{Y_1 \cdot Y_5 + Y_2 \cdot Y_5 + Y_3 \cdot Y_5 + Y_4 \cdot Y_5 + Y_3 \cdot Y_4} =$$

$$= \frac{s \cdot \dfrac{\omega_O}{Q}}{s^2 + s \cdot \dfrac{\omega_O}{Q} + \omega_O^2}$$

(3)

Equation (3) nominator must be a complex number in this case, therefore the admittances must be realized by resistors as follows: $Y_1 = G_1$. Another admittance can be chosen as a capacitor: $Y_4 = sC_4$ and $Y_2 = G_2$, $Y_5 = G_5$ must be realized as the resistors. The corresponding circuit diagram, in this case, is depicted in Fig. 7.
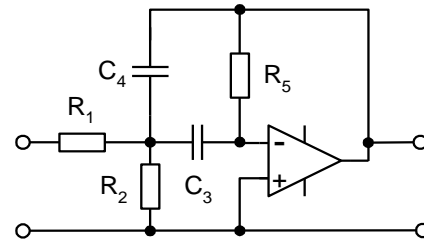

Fig.7 BP-H filter structure ver. 1.

The output voltage of frequency-independent input divider: R_1, R_2 is exciting other parts of this circuit, thus output voltage BP-H filter ver.1 is not zero at a higher frequency. Next, this circuit diagram will be analyzed with simulation by program MicroCap version 10, the result is given in Fig. 8.
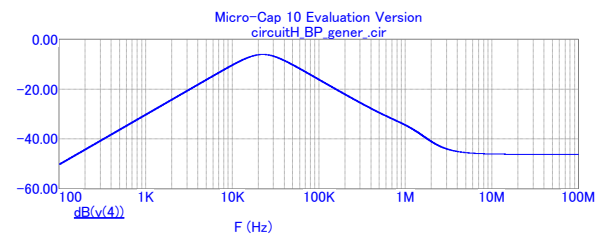

Fig.8 Filter BP-H structure ver. 1 frequency response.

As we can see, this biquad structure has not unfortunately a monotone increasing attenuation in stopband.

Consider now second one configuration (i.e. ver. 2), where nominator must be realized as: $Y_1 = G_1$, $Y_3 = sC_3$ as well, but in the denominator we can choose admittances: $Y_2 = sC_2$, $Y_5 = sC_5$ realized as capacitors and $Y_4 = G_4$ as the resistor. Thus, the corresponding circuit diagram is depicted in following Fig. 9.
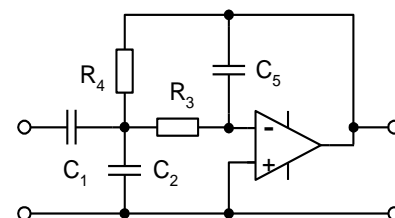

Fig.9 BP-H filter inversion structure (ver. 2).

Notice: As we can see in the comparison between Fig. 7 (ver. 1) and Fig. 9 (ver. 2), all passive

elements are inverted, because resistors and capacitors are changed.

The capacitors: C_1 and C_2, connected into the same node, are no short circuits in this case (in comparison with Fig. 5), because they are the input voltage divider. This divider is frequency independent, as is depicted in equation (4).

$$\frac{V_{C2}}{V_{IN}} = \frac{\frac{1}{sC_2}}{\frac{1}{sC_1}+\frac{1}{sC_2}} = \frac{\frac{1}{sC_2}}{\frac{sC_1+sC_2}{sC_1 \cdot sC_2}} = \frac{C_1}{C_1+C_2}$$

(4)

where: $s = j\omega$. Thus output voltage of divider: C_1, C_2 (i.e. V_{C2}) is exciting other parts of this circuit in all frequencies. In this reason, output voltage BP-H filter ver. 2 is therefore not zero at higher frequencies as well.

This circuit diagram will in next step analyzed by simulation with program MicroCap version 10, the result is given in Fig. 10. As we can see, these conclusions are verified by simulations very well, it is depicted, that this biquad structure has not a monotone increasing attenuation in stop band unfortunately as well.
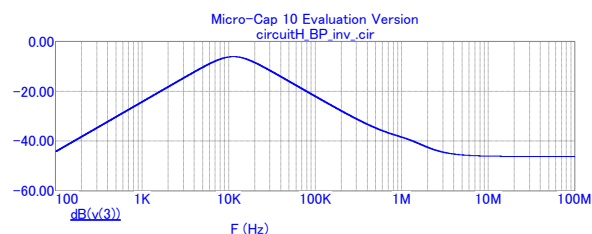

Fig.10 BP-H filter inversion structure frequency response (ver. 2).

For all simulations were the following value used: $R = 1 \cdot 10^3 \, \text{Ohm}$ for resistors and $C = 1 \cdot 10^{-9} \, \text{F}$ for capacitors, operational amplifier LM741 with $R_{OUTAC} = 50 \, \text{Ohm}$, $GBW = 1 \, \text{MHz}$.

4 Conclusion

All low-pass and band-pass Huelsman (i.e. multi feedback) structure are discussed. Since the main function of both the low-pass (and/or by-pass filter in especial cases) is to suppress the higher frequency, the Huelsmann low-pass structure ver. 1 and both the band-pass filter structure cannot be recommended as an ideal filter. Only low-pass structure ver. 2 has a monotone increasing attenuation in all

stopband (i.e. after the transient frequency of real operational amplifier as well), therefore only in this structure can be an ideal LP-H filter realised, as shows the results of the computer simulations. If the Huelsmann LP and/or BP structure filter is designed, the described reasons must be considered.

When the Huelsmann LP and/or BP structure filter is designed, we choose the same capacitors in the first step, the resistors are calculated from design equations next. The result from theoretical discussion and simulation is: it seems can be useful to find the new design process when will be $C_2 > C_1$ for BP-H ver. 2. Consider for example BP-H ver. 2, $C_2 = 10 \cdot C_1$, $R_4 = R_3$ where there is a frequency shift unfortunately, the result of simulation, in this case, is depicted in Fig. 11.
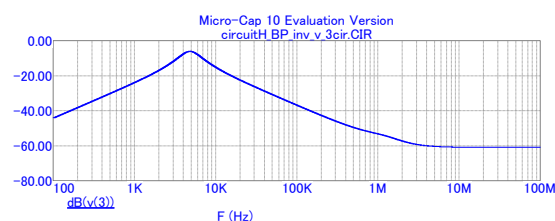

Fig.11 BP-H filter inversion structure frequency response (ver. 2), $R_4 = R_3$, $C_2 = 10 \cdot C_1$.

Thus, the attenuation is increasing from 46 dB to 61 dB as we can see. In this case transfer $\frac{V_{C2}}{V_{IN}}$ of the operational amplifier transient frequency ω_T will be not zero, but lowest. This can be in some cases quite sufficient.

Acknowledgement

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